Wind Energy Systems
Albert-Ludwigs-Universität Freiburg
Prof. Dr. Moritz Diehl, Nick Harder and Rachel Leuthold

Exercise Sheet 2: Wind Resource

1. First, let's consider some local wind speeds, to get an idea of its probability distribution.

   (a) To do this, find hourly wind speed data at 100m height for year 2022 at the coordinates of the Rosskopf wind turbines:
   `https://open-meteo.com/en/docs/historical-weather-api`.

   (b) Open the link and familiarize yourself with the website, see what data is available. Think about other measurements, that can be relevant to wind power output.

   (c) Download the data using the API or as CSV file.

   (d) Open the data in a programming environment, extract the wind speed measurements from the dataset, and remove the entries without valid data points.

   (e) Consider some basic statistical properties of the wind speed dataset. What are:

      i. the average wind speed $\overline{U}$?

      ii. the standard deviation σ of the wind speed measurements?

   (f) Plot a histogram of the wind speeds, normalized so as to represent the probability density function.

   (g) If you want to quickly get an idea of the mean wind speed corresponding to a particular Weibull distribution, which of the two parameters (shape k or scale c) should you look at?

   (h) Estimate the Rayleigh distribution for this dataset, and add a plot of that Rayleigh distribution to your histogram.

   (i) By comparing (visually) the histogram and Rayleigh distribution, do you think that the wind at this site is 'highly variable', 'somewhat variable' or 'not variable?' Please explain.

   (j) Where is the probability density suggested by this plot likely to be accurate, and where not? Please explain.

   (k) Because wind power grows with the cube of the wind speed, the average of cubed wind speeds is important for wind turbine siting decisions.

      i. Compute the average $\overline{U^3}$ of U_i^3, and the cubed average speed $\overline{U}^3$. Which number is higher?

2. Based on the wind data for a wind turbine at the height of 100m you decide that it would be more feasible to construct a wind turbine with a height of 80m. Now you are asked to present wind profiles and probability distribution for this height. How would you go about it?

   (a) For a quick assessment, you assume a logarithmic wind profile and using the two existing values you can use it to estimate the unknown wind speed. But where to find it?

   (b) Now after finding the second wind speed profile, how to estimate the new u_{80}?

   (c) **Bonus!** In addition, if you like, list pros and cons of the smaller turbine with lower hub height, and decide on your recommendation to the developer.

3. Regard a high-pressure region in the northern hemisphere at a latitude of $\phi = 50^o$. We have learnt that geostrophic wind - as well as its refinement, the gradient wind - is parallel to the isobars, and grows with the gradient of the pressure.

   (a) In what direction (as seen from above) does the air flow around the high pressure region described: clockwise or counterclockwise?

(b) The pressure gradient at a specific location A on the boundary of the high-pressure region is 5 Pa/km. What would be the geostrophic wind at this location?

(c) Would the gradient wind be faster or slower than the geostrophic wind at this location?